BALKAN PHYSICS LETTERS
© Bogazici University Press
BPL, **0** (0), pp. 1 - 4 (2008)
29 September 2008

REDISCOVERING STANDARD MODEL PHYSICS WITH THE ATLAS DETECTOR

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(received 28 October 2008 ; accepted 28 October 2008)

Abstract. - With its 14 TeV proton-proton center of mass energy, the LHC is a factory of Standard Model (SM) particles produced at previously inaccessible energy scales. The ATLAS experiment needs to perform a thorough analysis of these processes before exploring more exotic possibilities that the LHC may open doors to. W and Z bosons will initially be used as calibration samples to improve the understanding of the detector. Top quarks will also be copiously produced and will for the first time be calibration particles, whilst also yielding an important background to beyond the SM searches. Top quarks may also be produced with high transverse momenta, requiring novel methods to perform efficient top quark identification in the ATLAS detector. An overview will be given of the current status of the heavy gauge boson and top quark physics at ATLAS, in terms of both detector and expected precision measurements performance.

ATL-PHYS-PROC-2008-043
22 October 2008

The first measurements with the ATLAS detector [1] will be those of Standard Model processes. These early studies (documented in [2]) have three broad aims. The first is to study and further understand our knowledge of the proton, especially the parton density functions (pdfs). Secondly, these processes are excellent "standard candles" which can be used to calibrate and align the ATLAS detector. Thirdly, they are of interest as backgrounds to searches for the Higgs boson and new physics. This paper will discuss aspects of these measurements, focussing on measurements of the total W and Z cross sections and novel uses of high top quark statistics.

W and Z production

Production rates for W, Z bosons at the LHC will be significantly higher than at the Tevatron. Calculated to NNLO in QCD using the method in [4], $\sigma \times$ BR are 20.5 nb (W) and 2.02 nb (Z) for each leptonic decay channel, with an estimated uncertainty of

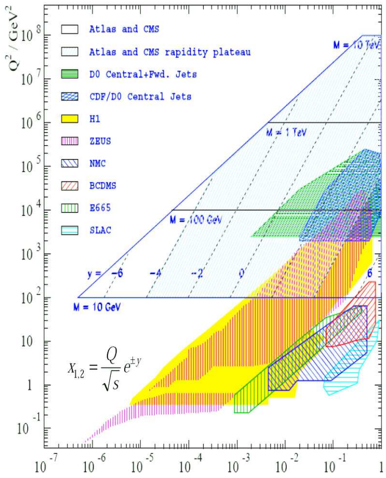

Figure 1: Kinematic coverage of the LHC and other relevant experiments, in the $x - Q^2$ plane.

about 3% from pdf model parameterisations. These processes probe a wide range of x values (Fig. 1, x is the fractional momentum of the proton carried by the partons in the hard scatter), and are particularly sensitive to low x gluon splitting.

The likely incomplete knowledge of detector performance at start-up led us to choose simple and robust event selection criteria for the first measurements of electroweak boson cross sections. The formula used in this measurement is $\sigma \times \mathrm{BR} = (N - B)/(L\epsilon A)$, where the raw number of candidate events N is corrected for backgrounds B, integrated luminosity L, efficiency ϵ and acceptance A. Here, A accounts solely for kinematic restrictions imposed by the p_T thresholds and pseudorapidity (η) cuts applied to the leptons, while ϵ includes reconstruction, identification and trigger efficiencies.

In these analyses, only electron and muon decay channels have been considered. Electrons are selected from electromagnetic calorimeter clusters loosely matched with tracks in the inner detector. In the W analysis, track quality cuts are added to reduce backgrounds. Muons are reconstructed by matching isolated tracks in the inner detector to those in the Muon Spectrometer.

For the Z analyses, two leptons must be reconstructed, each with p_T greater than 15 GeV (electrons) or 20 GeV (muons). For the W analyses, a lepton with $p_T > 25$ GeV is required, in addition to missing transverse energy ($\not\!\!E_T$) of at least 25 GeV from the neutrino.

Table 1: Projected event yield after selection and cross section uncertainties with 50 pb^{-1} for the inclusive boson cross section measurements.

	N events $\times 10^4$	$\Delta\sigma/\sigma$ stat.	syst.	lumi.
$W \to e\nu$	23	0.2%	5.2%	10%
$W \to \mu\nu$	30	0.2%	3.1%	10%
$Z \to ee$	2.7	0.8%	4.1%	10%
$Z \to \mu\mu$	2.6	0.8%	3.8%	10%

With relatively loose selection criteria, backgrounds must be carefully considered. Electroweak backgrounds can be reliably simulated as their production is well understood. Events involving QCD jets have very large and relatively poorly known cross sections. It is intended to estimate this contribution from data. For example, in the $W \to e\nu$ analysis, a QCD-enriched sample is obtained by taking events passing a photon trigger and applying vetos on W or Z boson candidates. Simulation indicates that the $\not\!\!E_T$ spectrum in this sample is similar to that of the QCD background in the analysis sample. The normalisation of this can be fixed using the low $\not\!\!E_T$ part of the spectrum.

Projected yields and uncertainties with 50 pb^{-1} of data are shown in Table 1. Statistical uncertainties are negligible. The dominant systematic uncertainties come from the event selection efficiency, backgrounds and theoretical uncertainties such as pdfs. These will reduce as more data accumulates. The large luminosity uncertainty will shrink once the ALFA experiment commences [5], ultimately giving the measurement sensitivity to pdfs and non-perturbative QCD effects, which can be probed by measuring the boson distributions.

To reduce dependency on simulation, data-driven techniques have been developed for measuring selection efficiencies in situ. Lepton trigger and offline identification efficiencies are determined using the "tag and probe" method. Briefly, a well-identified tag lepton is combined with a probe lepton which has a looser preselection applied. Then, the efficiency can be derived by testing how often the probe lepton passes trigger or offline identification cuts. To avoid bias, the event must be triggered using the tag lepton. Efficiencies can be extracted as a function of variables like the lepton p_T and pseudorapidity, with no detectable bias within current statistical uncertainties.

A key ingredient in W analyses is the reconstruction of $\not\!\!E_T$. For this, $Z \to \ell\ell$ events (with or without extra jet activity) are used. The $\not\!\!E_T$ is resolved along two axes, optimised to make best use of the excellent angular resolution of the ATLAS inner detector. As no genuine $\not\!\!E_T$ is expected in these events, any observed $\not\!\!E_T$ is assumed to arise from detector resolution, allowing the $\not\!\!E_T$ bias and resolution to be extracted as a function of the total hadronic energy in the event.

Measuring the multiplicity and p_T spectra of jets produced in association with W and Z bosons will be a vital task in ATLAS, to test perturbative QCD and provide information on these background processes for top measurements and searches for physics beyond the Standard Model. For these measurements to be sensitive to QCD effects, the jet energy scale will need to be controlled at the 5% level or better.

Studies of the hadronically decaying top quark

The very large $t\bar{t}$ cross section at the LHC, approximately 830 pb [6], will pose new challenges but also open new possibilities for improving detector understanding. This is possible because each top quark in a $t\bar{t}$ event decays with essentially 100% probability to a real W boson and b quark. If one W boson decays leptonically, the event can be triggered, permitting detailed and unbiased study of the other, hadronically decaying, W boson, utilising its well-measured mass and decay properties.

Hadronic decays of the W involving b quarks are strongly suppressed, making this W a clean source of light quark jets, which can be used to fix the light jet energy scale. Template histograms are made and fitted to the data, taking into account the detector resolution, smearing of jet angles compared to the initial quarks and correlations between the two jet energies. It has been found using simulation that the energy scale estimate is not very sensitive to the initial assumptions used to make the templates, but that a very pure W selection is required. Assuming that this is possible, the method could achieve a precision of 2% on the absolute energy scale for light quark jets with just 50 pb^{-1} of data.

The high $t\bar{t}$ cross section at the LHC also means we will see highly boosted top quarks. With high transverse momenta, it becomes increasingly likely that a hadronically decaying top quark will be reconstructed as one or two jets, rather than three. This poses new challenges for jet reconstruction [3]. Two interesting discriminating variables are the jet mass and the energy scale at which subjets become resolved. For a top "monojet", the jet mass should be around m_t, and subjets should be resolvable at scales around $m_t/2$ and $m_W/2$. Signal and background jet selection efficiencies are shown in Fig. 2 for a first attempt at a selection based on these and similar variables. This high p_T $t\bar{t}$ selection will be further enhanced by reconstructing the lepton from the other W decay and the displaced vertex from the b quark in the monojet.

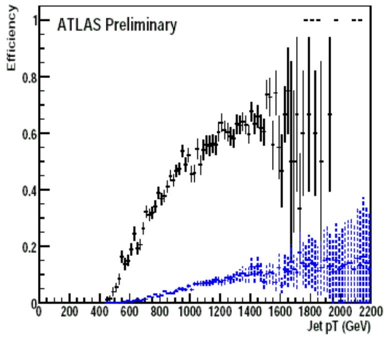

Figure 2: Selection efficiency for top quark monojets (solid, black) and background jets (dashed, blue) as a function of reconstructed p_T of the jet. From [3].

Conclusion

Understanding Standard Model physics is essential for the ATLAS physics programme. A selected range of physics and performance topics currently under study were presented, with an emphasis on early measurements. Based on detailed simulation studies, it has been concluded that except for luminosity uncertainties, we expect to be able to measure electroweak boson cross sections with a precision of 5% or better with 50 pb^{-1} of data. This is made possible only using data-driven methods for determining selection efficiencies and backgrounds. Finally, proposed measurements of the light jet energy scale and high p_T top quarks have been described, both possible due to the extremely high $t\bar{t}$ production rate at the LHC.

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